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(54) **HIGH MANGANESE STEEL FOR LOW TEMPERATURE, HAVING EXCELLENT SURFACE QUALITY, AND MANUFACTURING METHOD THEREFOR**

MANGANSTAHL FÜR TIEFTEMPERATUREN MIT AUSGEZEICHNETER OBERFLÄCHENQUALITÄT UND VERFAHREN ZU SEINER HERSTELLUNG

ACIER À HAUTE TENEUR EN MANGANÈSE POUR BASSE TEMPÉRATURE, AYANT UNE EXCELLENTE QUALITÉ DE SURFACE, ET SON PROCÉDÉ DE FABRICATION

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Description

[Technical Field]

5 **[0001]** The present invention relates to a high manganese steel for low temperature applications, which can be utilized in liquefied gas storage tanks and transportation facilities, in a wide range of temperatures from low temperature to room temperature, more specifically, to a high manganese steel for low temperature applications having excellent surface quality, and a method of manufacturing the same.

10 [Background Art]

[0002] There has been an increased interest in energy sources, such as LNG and LPG, as alternative energy sources, due to tightening regulations on environmental pollution and safety as well as the exhaustion of fossil fuels. As demand for non-polluting fuels, such as natural gas and propane gas, which are carried in a low temperature liquid state, increases, production and material development of storage and transportation devices is increasing for non-polluting fuels.

15 **[0003]** Materials having excellent mechanical properties such as strength and toughness at low temperatures are used in low temperature storage tanks, and representative materials may be aluminum alloy, austenitic stainless steel, 35% Inva steel, and 9% Ni steel.

[0004] Among such materials, 9% nickel steel is the most widely used, in terms of economic feasibility and weldability. As most of these materials are high in terms of the amount of nickel added thereto, they may be expensive; thus, it is urgent to develop alternative materials having excellent yield strength and low temperature toughness.

20 **[0005]** Meanwhile, one method for manufacturing a material having high low temperature toughness to allow the material to have a stable austenite structure at low temperatures.

[0006] An example thereof is a technique of stabilizing austenite by adding large amounts of carbon and manganese. When large amounts of carbon and manganese are added to stabilize austenite, however, slabs to products have an austenite single phase, that is, phase transformation may not occur.

[0007] Since phase transformation may not occur, the slab may have a coarse casting structure. For this reason, surface grain boundary cracking occurs when the slab is hot-rolled. Further, the slab, which does not involve phase transformation, has a coarse casting structure, and thus has poor high temperature ductility.

30 **[0008]** When surface grain boundary cracking occurs during hot-rolling of the slab, the surface quality of the steel is deteriorated, resulting in thickness irregularities of a final structure.

[0009] In particular, such thickness irregularities may cause a significant problem in the structural design and use of a structure requiring pressure resistance through securing a uniform thickness of steel, such as a low temperature pressure vessel.

35 (Prior Art)

[0010]

40 (Patent Document 1) Korean Laid-Open Patent Publication Application No. 2011-0009792.
WO 2016/105002 A1 discloses a steel for low temperature environments including (in weight %) Mn 15 - 35, Ti 0.01 - 0.5, Cu >0 - 5, N 0.003 - 0.2, 23.6C + Mn \geq 28, 33.5C - Mn \leq 23 and balance Fe and optional impurities, the steel having a single phase austenite microstructure.

45 [Disclosure]

[Technical Problem]

50 **[0011]** An aspect of the present disclosure is to provide a high manganese steel for low temperature applications having not only excellent yield strength and impact toughness but also excellent surface quality.

[0012] Another aspect of the present disclosure is to provide a method for manufacturing a high manganese steel for low temperature applications having not only excellent yield strength and impact toughness but also excellent surface quality at a low price.

55 [Technical Solution]

[0013] The invention is defined in the claims.

[Advantageous Effects]

[0014] According to an aspect, a high manganese steel for low temperature applications, having not only excellent yield strength and impact toughness but also excellent surface quality, may be provided at a low price.

[Brief Description of The Drawings]

[0015] FIGS. 1 and 2 illustrate microstructures of a slab before and after forging; FIG. 1 illustrates a microstructure of a slab before forging, while FIG. 2 illustrates a microstructure of a slab after forging.

[0016] FIGS. 3 and 4 illustrate microstructures of a conventional steel and a steel appropriate to the present disclosure; FIG. 3 illustrates a microstructure of the conventional steel (Comparative Example 2) in which coarse grains of austenite are formed, while FIG. 4 illustrates a uniform structure of austenite of the steel (Inventive Example 3) to which forging of a slab is applied according to the present invention.

[0017] FIGS. 5 and 6 are photographic images illustrating examples of result of determining whether surface irregularities is generated; FIG. 5 illustrates an example of a case in which surface irregularities is generated, while FIG. 6 illustrates an example of a case in which surface irregularities is not generated.

[0018] FIG. 7 is a graph illustrating a change in high temperature ductility of a slab according to a microstructure grain size of a surface layer of the slab.

[Best Mode for Invention]

[0019] The present invention relates to a high manganese steel for low temperature applications having excellent surface quality and a manufacturing method thereof. Preferred embodiments of the present invention will be described.

[0020] The embodiments are provided to describe in detail the present invention to those skilled in the art.

[0021] The present invention is preferably applied to materials including, for example, liquefied petroleum gas and liquefied natural gas, for use in low temperature components such as fuel tanks, storage tanks, ship membranes and transport pipes for storing and transporting at low temperatures.

[0022] When stabilizing austenite by adding large amounts of carbon and manganese as in the present invention, slabs to products have an austenite phase, that is, those are not subject to phase transformation.

[0023] As phase transformation does not occur, the slab has a coarse casting structure. For this reason, surface grain boundary cracking occurs when hot-rolling the slab.

[0024] When the cracking occurs during hot-rolling, surface quality of the steel may deteriorate, thereby giving rise to thickness irregularity of a final structure product. Further, the slab, which does not involve phase transformation, has the coarse casting structure, and thus does not have superior high temperature ductility.

[0025] In this regard, the present inventors conducted research and experiments to develop a high manganese steel for low temperature applications having not only high yield strength and excellent impact toughness but also excellent surface quality, and as a result, completed the present invention.

[0026] Main concepts of the present disclosure are as follows.

1) In order to stabilize the austenite structure, contents of C, Mn and Cu are particularly controlled. Austenite stabilization may serve to excellent low temperature toughness.

2) A size of a microstructure of the steel and a number of coarse grains are particularly controlled. This may serve to improved surface quality of the steel.

3) Cooling conditions of the hot-rolled steel are particularly controlled. This may serve to prevention of carbide formation in the grains, which may improve impact toughness.

4) The slab is subject to deformation prior to the hot-rolling thereof, such that a recrystallization microstructure is formed on the surface layer portion of the slab. An example of the deformation treatment is rough rolling under high reduction conditions or high temperature forging under high reduction conditions.

By deforming the slab, for example, rough rolling under high reduction conditions, forging under high reduction conditions, or the like, to form a recrystallization microstructure on the surface layer of the slab, before the slab is hot rolled, coarse grain cracking may be prevented from being generated and spread along the casting structure, thereby improving surface quality of the steel. Further, as the recrystallization microstructure is formed on the surface layer of the slab, high temperature ductility of the slab may be improved.

5) Hot-rolling conditions are particularly controlled. In particular, a final rolling temperature is controlled depending on a final steel thickness during hot rolling. This may secure high strength.

[0027] Hereinafter, the high manganese steel for low temperature applications according to an embodiment will be described.

5 [0028] A high manganese steel for low temperature applications according to an embodiment of the present invention contains 0.3 wt% to 0.8 wt% of C, 18 wt% to 26 wt% of Mn, 0.01 wt% to 1 wt% of Si, 0.01 wt% to 0.5 wt% of Al, 0.1 wt% or less of Ti (excluding 0%), 1 wt% to 4.5 wt% of Cr, 0.1 wt% to 0.9 wt% of Cu, 0.03 wt% or less of S (excluding 0%), 0.3 wt% or less of P (excluding 0%), 0.001 wt% to 0.03 wt% of N, 0.004 wt% or less of B (excluding 0%), and a remainder
10 of Fe and other inevitable impurities, wherein a microstructure comprises an austenite single phase structure, an average grain size of the austenite is 20 μm to 50 μm , a number of austenite grains having a grain size of 50 μm or more is less than 1 per cubic centimeter, wherein the high manganese steel further comprises 1 volume% or less (including 0%) of a precipitate, wherein the high manganese steel has rolling direction impact toughness of 100 J or higher at -196°C , wherein the high manganese steel has an anisotropy index of 0.6 or higher, wherein the anisotropy index is a ratio of thickness direction impact toughness at -196°C to rolling direction impact toughness at -196°C , and wherein the high manganese steel has yield strength of 400 MPa or higher.

15 [0029] Hereinafter, ingredients of the high manganese steel for low temperature applications and contents thereof will be described in more detail. Unless otherwise indicated, percentages indicating the content of each element are based on weight.

C: 0.3 wt% to 0.8 wt%

20 [0030] Carbon (C) is an element for stabilizing austenite and securing strength. When a content thereof is less than 0.3 wt, stability of the austenite is insufficient, and ferrite or martensite may form, thereby reducing low temperature ductility. Meanwhile, when a content thereof exceeds 0.8 wt%, carbides are formed, which may give rise to surface defects. Accordingly, the content of C is limited to 0.3 wt% to 0.8 wt%.

Mn: 18 wt% to 26 wt%

25 [0031] Manganese (Mn) is an important element for stabilization of the austenite structure. As ferrite needs to be prevented from being formed and stability of the austenite needs to be increased to secure low temperature ductility, at least 18 wt% needs to be added. When the content of Mn is less than 18 wt%, an ϵ -martensite phase and an α' -martensite phase are formed and low temperature ductility is reduced. In contrast, when the content thereof is greater than 26 wt%, a manufacturing cost greatly increases, and internal oxidation is severely generated when the slab is heated during the
30 hot rolling, which leads to deteriorated surface quality. Accordingly, the content of Mn is limited to 18 wt% to 26 wt%.

Si: 0.01 wt% to 1 wt%

35 [0032] Silicon (Si) is an element improving castability of molten steel, and in particular, effectively increasing strength of the steel while being added to austenite steel. However, when Si is added in an amount greater than 1 wt%, stability of austenite decreases and toughness may be reduced. Accordingly, an upper limit of the Si content is controlled to be 1 wt%.

Al: 0.01 wt% to 0.5 wt%

40 [0033] Aluminum (Al), in an appropriate amount thereof, is an element stabilizing austenite and affecting carbon activity in the steel to effectively inhibit the formation of carbides, thereby increasing toughness. When more than 0.5 wt% of Al is added, castability and surface quality may deteriorate through oxides and nitrides. Accordingly, an upper limit of the Al content is limited to 0.5 wt%.

45 Ti: 0.1 wt% or less (excluding 0%)

50 [0034] Titanium (Ti) is an element forming a precipitate individually or in combination to refine the austenite grain, thereby increasing strength and toughness. Further, when a sufficient number of sites for precipitate formation are present in the austenite grain, Ti forms fine precipitates inside the grain to improve strength through precipitate hardening. When more than 0.1 wt% of Ti is added, a large amount of oxide is produced in steelmaking, causing processing and cast steel-related problems during continuous casting. Alternately, carbonitrides are coarsened, causing deterioration of steel elongation, toughness and surface quality. Accordingly, the content of Ti is limited to 0.1 %wt or less.

55 Cr: 1 wt% to 4.5 wt%

[0035] Chromium (Cr) is superior in terms of strength improvement through strengthening of a solid solution in the austenite structure. As Cr has a corrosion resistance effect, surface quality may be effectively improved in high temper-

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ature oxidation. In order to obtain such an effect, Cr is added in an amount of at least 1 wt%. Meanwhile, when an amount of Cr exceeding 4.5 wt% may be advantageous for carbide production, causes a problem of deteriorated cryogenic toughness. Accordingly, the content of Cr is limited to 1 wt% to 4.5 wt%

5 Cu: 0.1 wt% to 0.9 wt%

[0036] Copper (Cu), together with Mn and C, is an element which improves low temperature toughness while stabilizing austenite. Due to low solid solubility in carbides and slow diffusion in austenite, Cu is concentrated at an interface between austenite and nucleated carbides. By interfering with the diffusion of carbon, Cu effectively slows carbide growth and suppresses carbide formation. Accordingly, Cr is used together with Cr. In order to acquire such an addition effect, Cu is added in an amount of at least 0.1 wt% or more. Meanwhile, when Cu is added in an excessive amount of 0.9 wt%, surface quality may be deteriorated due to hot shortness. Accordingly, the content of Cu is limited to 0.1 wt% to 0.9 wt%.

15 S: 0.03 wt% or less (excluding 0%)

[0037] Sulfur (S) needs to be controlled to be in an amount of 0.03 wt% or less for inclusion control.

[0038] When a content of S exceeds 0.03 wt, hot shortness may occur and surface quality may be deteriorated.

20 P: 0.3 wt% or less (excluding 0%)

[0039] Phosphorous (P) is an element promoting that segregation easily occurs, and lowers cracking and weldability during casting. To prevent the same, a content thereof needs to be controlled to 0.3 wt% or less. A content of P exceeding 0.3 wt% may reduce castability. Accordingly, an upper limit thereof is limited to 0.3 wt%.

25 N: 0.001 wt% to 0.03 wt%

[0040] Nitrogen (N), together with C, is an element stabilizing austenite and improving toughness. In particular, N is a greatly advantageous element for enhancing strength through solid solution strengthening or precipitate formation such as carbon. However, when added in an excessive amount of more than 0.03 wt%, physical properties and surface quality deteriorate due to coarsening of carbonitrides. Accordingly, an upper limit thereof is limited to 0.03 wt%. Meanwhile, when added in an amount of less than 0.001 wt%, the effect is insignificant. Accordingly, a lower limit thereof is limited to 0.001 wt%.

35 B: 0.004 wt% or less (excluding 0%)

[0041] Boron (B) has a significant effect on surface quality improvement by suppressing grain boundary fracture through strengthening of grain boundaries, but decreases toughness and weldability due to formation of coarse precipitates when excessively added. Accordingly, the content thereof is limited to 0.004 wt% or less.

40 **[0042]** In addition to the above, a remainder of Fe and inevitable impurities are included. However, in a conventional manufacturing process, impurities, which are not intended from the raw material or the surrounding environment, may be inevitably mixed, and thus cannot be excluded.

[0043] The microstructure of the high manganese steel for low temperature applications according to an embodiment is an austenite single phase, and an average grain size of the austenite structure is 20 μm to 50 μm .

45 **[0044]** A number of the austenite grains having a grain size of 50 μm or more is less than 1 per cm^2 .

[0045] When an average grain size of the austenite structure exceeds 50 μm , high density of the coarse grains causes non-uniform deformation during processing into a structure, which may result in deterioration of the surface quality after processing. Accordingly, the average grain size is limited to 50 μm or less. In contrast, strength of the steel increases accordingly as the average grain size of the austenite structure decreases, but precipitation of grain boundary carbide is facilitated by grain refinement, and low temperature toughness may become inferior due to the increased strength. Accordingly, the average grain size of the austenite structure is limited to 20 μm or more. In this regard, the average grain size of the austenite structure is 20 μm to 50 μm , and preferably 20 μm to 30 μm .

[0046] Meanwhile, when a number of the grains of the austenite structure, which have a grain size of at least 50 μm , is 1 or more per cm^2 , high density of the coarse grains may deteriorate the surface quality after processing into a structure. Accordingly, the number of the grains of the austenite, which have a grain size of at least 50 μm , is limited to less than 1 per cm^2 . More preferably, the number of the grains of the austenite structure, which have a grain size of at least 30 μm may be less than 1 per cm^2 .

[0047] 1 vol% or less precipitates may be contained in the high manganese steel. When the precipitate is contained

in an amount exceeding 1 vol%, low temperature toughness may be deteriorated. Accordingly, the amount of the precipitate is limited to 1 vol% or less (excluding 0%).

[0048] A thickness of the high manganese steel may be 8.0 mm or more, preferably 8.0 mm to 40 mm.

[0049] The high manganese steel for low temperature applications according to the present invention has an impact toughness (preferably a Charpy impact absorption energy) of 100 J or more in the rolling direction (RD) at -196°C.

[0050] As used herein, an anisotropy index refers to a ratio of thickness direction (TD) impact toughness at -196°C to rolling direction (RD) impact toughness at -196°C. Specifically, the anisotropy index of the steel in the present invention refers to a value obtained by dividing TD Charpy impact absorption energy at -196°C by RD Charpy impact absorption energy at -196°C.

[0051] When the anisotropy index is below a certain level, securing the physical properties may be problematic in a final product. That is, an anisotropy index below a certain level may make it difficult to secure target Charpy impact absorption energy according to a direction of a material of a final product. Accordingly, the high manganese steel for low temperature applications of the present invention is limited to a certain level or more, thereby effectively preventing non-uniform Charpy impact absorption energy according to the direction of a material of the final product. A lower limit of the material anisotropy index is 0.6, and preferably 0.8, to prevent non-uniform physical properties of the final product according to the direction of the material.

[0052] Hereinbelow, a method for manufacturing a high manganese steel for low temperature applications will be described.

[0053] A method for manufacturing a high manganese steel for low temperature applications according to another embodiment includes preparing a slab comprising 0.3 wt% to 0.8 wt% of C, 18 wt% to 26 wt% of Mn, 0.01 wt% to 1 wt% of Si, 0.01 wt% to 0.5 wt% of Al, 0.1 wt% or less of Ti (excluding 0%), 1 wt% to 4.5 wt% of Cr, 0.1 wt% to 0.9 wt% of Cu, 0.03 wt% or less of S (excluding 0%), 0.3 wt% or less of P (excluding 0%), 0.001 wt% to 0.03 wt% of N, 0.004 wt% or less of B (excluding 0%), and a remainder of Fe and other inevitable impurities; deformation application involving applying a deformation to the slab such that a fine recrystallization structure is formed on a surface layer portion of the slab; air cooling involving air-cooling the slab on which the fine recrystallization structure is formed on the surface layer portion thereof to room temperature; reheating involving heating the air-cooled slab to 1100°C to 1250°C; hot rolling involving finish-rolling the reheated slab at 850°C to 950°C to obtain a hot-rolled steel; and accelerated cooling involving accelerated-cooling the hot-rolled steel at a cooling speed of 10°C/sec or more to an accelerated cooling termination temperature of 600°C or less.

Deformation application and air-cooling

[0054] A slab is applied with deformation so that a recrystallization microstructure is formed on a surface layer portion of the slab, followed by air-cooling to room temperature. As used here, the slab surface layer portion refers to a region of the slab surface layer portion up to 2 mm from the surface in a slab thickness direction.

[0055] As the slab contains a coarse casting structure, cracking is likely to occur and high temperature ductility is inferior when hot rolling. In this regard, deformation is applied to the slab such that a recrystallization microstructure is formed on the surface layer portion of the slab, thereby preventing cracking from occurring during hot rolling and improving high temperature ductility. A recrystallization microstructure may be formed in a region other than the surface layer portion.

[0056] The deformation application is performed such that a recrystallization structure in which a number of grains having a grain size of at least 150 μm is less than 1 per cm^2 . When a number of grains having a grain size of at least 150 μm is one or more, high temperature ductility deteriorate due to coarse grains, and cracking and propagation are generated during hot-rolling, thereby adversely affecting surface quality of a product. An average grain size of the surface layer portion of the slab after the deformation application may be 100 μm or less.

[0057] A treatment for the deformation application is not particularly limited, and any treatment is feasible as long as deformation is applied to the slab before reheating the slab and a recrystallization microstructure is formed on the surface layer portion of the slab.

[0058] An example of the deformation application is rough rolling at 1000°C to 1200°C under high reduction conditions. When a temperature for the rough rolling under the high reduction conditions is less than 1000°C, a treatment temperature is too low to obtain a recrystallization microstructure and deformation resistance may excessively increase during rough rolling. When the temperature exceeds 1200°C, it may be advantageous in obtaining the recrystallization microstructure, but may cause deeper grain boundary oxidation and partial melting in a segregation zone in the cast structure, resulting in surface quality deterioration.

[0059] When the slab is rough-rolled under high reduction conditions as described above, recrystallization occurs at least on the surface layer portion of the slab, thereby forming a recrystallization microstructure on the surface layer portion of the slab.

[0060] Another example of the deformation application is high temperature forging at 1000°C to 1200°C. When the forging is performed at a temperature less than 1000°C, a treatment temperature is too low to obtain a recrystallization

microstructure and deformation resistance may increase excessively during forging. When the temperature exceeds 1200°C, it may be advantageous in obtaining the recrystallization microstructure, but may cause deeper grain boundary oxidation and partial melting in a segregation zone in the cast structure, resulting in surface quality deterioration

[0061] When the slab is forged at a high temperature, recrystallization occurs at least on the surface layer portion of the slab, thereby forming a recrystallization microstructure on the surface layer portion of the slab.

[0062] The deformation application is performed such that a number of austenite grains having a grain size of 150 μm or more formed on the surface layer portion of the slab be less than 1 per cm². An average grain size on the surface layer portion of the slab after deformed may be 100 μm or less.

[0063] The deformation application is performed such that a thickness reduction rate is 15% with respect to an initial slab. When the thickness reduction rate is less than too small, sufficient deformation cannot be secured, thereby making it difficult to obtain a recrystallization structure of the surface layer. However, an excessive thickness reduction rate causes the microstructure of the final steel to be excessively refined, thereby deteriorating low temperature toughness. In this regard, the thickness reduction rate is limited to 50% or less. Accordingly, the thickness reduction rate is 15% to 50%.

[0064] The slab in which a recrystallization microstructure is formed on the surface layer may have a cross-section reduction rate (high temperature ductility) of at least 60% at 1100°C.

[0065] Another example of the deformation application is a shot blasting method.

Slab reheating

[0066] As previously described, the air-cooled slab is reheated to 1100°C to 1250°C. When a slab reheating temperature is too low, a rolling load may be excessively applied during hot rolling. In this regard, the reheating temperature is at least 1100°C. The higher the heating temperature is, the easier the hot rolling is; however, in the case of steel, as the steel of the present invention, which contains a large amount of Mn, may have deteriorated surface quality due to severe internal grain boundary oxidation during high temperature heating. Accordingly, the reheating temperature is 1250°C or less.

Hot-rolling

[0067] As previously described, the reheated slab is finish hot-rolled at 850°C to 950°C to obtain hot-rolled steel. A thickness thereof may be at least 8 mm, preferably 8 mm to 40 mm.

[0068] During hot rolling, as a finish hot rolling temperature increases, deformation resistance decreases, thereby making the rolling easier; however, a higher rolling temperature may deteriorate the surface quality. In this regard, the finish rolling is performed at a temperature of 950°C or less. Meanwhile, when the finish hot rolling temperature is too low, a load increases during the rolling. In this regard, the finish rolling is performed at a temperature of 850°C or above.

[0069] A rolling temperature may be controlled according to a thickness of the final steel during hot rolling. This may improve strength.

[0070] In the hot rolling of the present invention, a final pass rolling temperature during hot finish rolling may be 850°C or above and less than 900°C when a final thickness of the steel is 18t (t: steel thickness (mm)) or above, and a final pass rolling temperature during hot finish rolling may be 900°C to 950°C when a final thickness of the steel is less than 18t (t: steel thickness (mm)).

[0071] When the final thickness of the steel is greater than 18t (t: steel thickness (mm)), sufficient strength cannot be obtained at a final pass rolling temperature of at least 900°C during finish hot rolling. When the final thickness of the steel is less than 18t (t: steel thickness (mm)), strength may greatly increase at a final pass rolling temperature of less than 900°C during finish hot rolling, thereby reducing low temperature impact toughness.

[0072] When the final thickness of the steel is greater than 18t (t: steel thickness (mm)), carbides may be precipitate at a final pass rolling temperature of less than 850°C, which is lower than a temperature of carbide formation. The carbide precipitation may reduce low temperature impact toughness. When the final thickness of the steel is less than 18t (t: steel thickness (mm)), the rolling is performed for a short period of time at a final pass rolling temperature of greater than 950°C, thereby making it difficult to secure a temperature.

[0073] It is preferable that when a final thickness of the steel is 18t (t: steel thickness (mm)) or above, the hot rolling be performed at a temperature below a non-recrystallization temperature (T_{nr}) such that a reduction ratio is at least 40% of a total reduction rate. When the reduction ratio is less than 40% at a temperature lower than T_{nr}, insufficient accumulation of dislocations may occur, thereby leading to low strength.

Accelerated cooling

[0074] The hot-rolled steel is accelerated-cooled at a cooling speed of 10°C/sec or more to a accelerated cooling termination temperature of 600°C or less. The hot-rolled steel is a steel containing 1 wt% to 4.5 wt% of Cr and containing

C and thus is essentially subject to accelerated cooling so as to prevent carbide precipitates which may reduce low temperature ductility.

5 **[0075]** When the cooling speed of accelerated cooling is less than 10°C/sec, carbides are precipitated in the grain boundaries, which may deteriorate impact toughness. The cooling speed may be 10°C/sec to 40°C/sec. When the accelerated cooling termination temperature is greater than 600°C, carbides are precipitated in the grain boundaries due to said reason, and impact toughness may deteriorate. The accelerated cooling termination temperature is up to 600°C, preferably 300°C to 400°C.

10 **[0076]** The steel manufactured as previously described has an austenite single phase, and an average grain size of the austenite structure is 20 μm to 50 μm, preferably 20 μm to 30 μm. Such manufactured steel has a microstructure whose number of the austenite grain having a grain size of at least 50 μm, is less than 1 per cm².

[0077] Such manufactured steel has an impact toughness of 100 J or higher at -196°C in a rolling direction (RD), and an anisotropy index of 0.6 or higher, more preferably 0.8 or higher, at -196°C, where the anisotropy index is a ratio of thickness direction (TD) impact toughness at -196°C to the RD impact toughness at -196°C.

15 **[0078]** Such manufactured steel has a yield strength of 400 MPa or higher.

[Mode for Invention]

20 **[0079]** Hereinbelow, the present disclosure will be described in more detail with reference to embodiments. The example embodiment below is merely an example for describing the present disclosure in detail, and may not limit the scope of rights of the present invention.

[0080] A slab having the steel composition of Table 1 is forged under the conditions of Table 2 and air-cooled to room temperature, and then reheated, hot rolled and cooled under the conditions of Table 2 to obtain a hot-rolled steel having a thickness of Table 2.

25 **[0081]** A number of austenite grains having a grain size of at least 150 μm on the slab surface layer before the slab is heated and high temperature ductility of the slab were evaluated. A result thereof is shown in Table 2 below.

30 **[0082]** Meanwhile, a number of austenite grains having a grain size of at least 50 μm and that of at least 30 μm (per cm²), an average grain size, a precipitate percentage (volume%), yield strength, Charpy impact toughness and surface irregularities were observed for the manufactured hot-rolled steel and the result thereof is shown in Table 3 below. The Charpy toughness was measured for the hot-rolled steel in the rolling direction and that in the thickness direction. An anisotropy index was measured by calculating Charpy impact absorption energy at -196°C in the TD to that in the RD.

35 **[0083]** The high temperature ductility (cross sectional reduction rate (%)) was measured at a strain rate of 1/s at 1100°C, and the Charpy impact toughness was measured at -196°C. The surface irregularities, as illustrated in FIGS. 5 and 6, were evaluated by bending the steel and observing with naked eye. FIG. 5 illustrates an example of a case in which surface irregularities occurred, and FIG. 6 illustrates an example of a case in which surface irregularities did not occur.

[0084] Meanwhile, Inventive Example 3, subject to forging, was observed with respect to the microstructure of the slab before and after forging, and a result thereof is shown in FIG. 1. FIG. 1 illustrates the slab microstructure before forging, and FIG. 2 illustrates the slab microstructure after forging.

40 **[0085]** Inventive Example 3, to which the forging treatment is applied, and Comparative Example 2, to which the forging treatment is not applied, were observed with respect to the structure of the steel surface layer after hot rolling, and a result thereof is shown in FIGS. 3 and 4. FIG. 3 represents Comparative Example (2) and FIG. 4 represents Inventive Example (3).

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[Table 1]

Steel	Steel composition (wt%)										
	C	Mn	Si	Al	Ti	Cr	Cu	S	P	N	B
1	0.45	24.5	0.3	0.0271	0.031	3.7	0.50	0.0022	0.0178	0.0112	0.0029
2	0,45	24.5	0.3	0.0377	0.031	3.8	0.50	0.0012	0.0252	0.0134	0.0025
3	0.45	24.5	0.3	0.0362	0.032	3.7	0.48	0.0014	0.0239	0.0152	0.0026
4	0.45	24.5	0.3	0.0371	0.021	3.5	0.48	0.0007	0.027	0.0136	0.0025
5	0.45	24.5	0.3	0.0334	0.002	3.3	0.41	0.0013	0.0135	0.0201	0.0025
6	0.45	24.5	0.3	0.0278	0.029	3.6	0.53	0.0029	0.0192	0.0161	0.0018
7	0.45	24.5	0.3	0.0451	0.003	3.3	0.41	0.0010	0.0166	0.0172	0.0025
8	0.45	24.5	0.3	0.0266	0.029	3.3	0.42	0.0011	0.0164	0.0151	0.0028

[Table 2]

	Steel	Forging temp (1100°C)	Forging thickness reduction rate	No. of slab surface layer coarse grain having grain size of 150 μm	Slab high temperature ductility (%)	Reheating temperature (°C)	Finish rolling temperature (°C)	Reduction rate at T _{nr} or lower (%)	Cooling speed (°C/sec)	Cooling termination temperature ((°C)	Steel thickness (mm)	Miscellaneous
5												
10												
15												
20												
25	1	Not App	-	10	24	1200	930	35	25	380	21	CE1
30	2	Not App	-	5	35	1180	920	46	33.5	400	15	CE2
35	3	App	52	0.03	80	1180	800	45	8	400	20	CE3
40	4	App	28	0.1	89	1180	930	55	33.5	380	15	IE1
45	5	App	28	0.1	90	1200	930	30	23.9	372	27	I _{REF}
50	6	App	28	0.1	87	1200	862	45	23.9	364	27	IE3
55	7	App	28	0.1	85	1220	860	55	23.9	391	27	IE4
	8	App	28	0.1	80	1220	850	50	15	350	36	IE5

*CE: Comparative Example, **IE: Inventive Example

[Table 3]

Type	No. of steel coarse grain having grain size of 50 μm or more (/cm ²)	No. of steel coarse grain having grain size of 30 μm or more (/cm ²)	Average grain size of steel (μm)	Precipitate percentage (vol%)	Yield strength (MPa)	-196°C Impact toughness (J, RD)	-196°C Impact toughness (J, TD)	Anisotropy index	Surface irregularities	Misc.
1	4	6	55	<1%	384	100	57	0.57	Irr	CE1
2	3	5	52	<1%	410	151	85	0.56	Irr	CE2
3	0.02	0.03	18	4%	565	49	43	0.87	Non-irr	CE3
4	0.1	0.1	24	<1%	465	146	122	0.84	Non-irr	IE1
5	0.1	0.5	29	<1%	356	103	91	0.88	Non-irr	REF
6	0.1	0.1	27	<1%	410	130	119	0.92	Non-irr	IE3
7	0.1	0.1	26	<1%	462	110	97	0.88	Non-irr	IE4
8	0.1	0.1	26	<1%	433	100	101	1.01	Non-irr	IE5

[0086] In the tables REF is a Reference Example.

[0087] As indicated in Tables 1 to 3 above, Inventive Examples 1, 3 and 4, which satisfy the steel composition and manufacturing conditions of the present invention, have less than 1 coarse grain having a grain size of 150 μm or more per cm² on the surface layer portion of the slab, and an average grain size of the steel is 50 μm or less, and a number of the coarse grain having a grain size of at least 50 μm and that of at least 30 μm are less than

1. In the case of Inventive Examples (1 and 3 to 5), not only are yield strength and impact toughness excellent, but also no surface irregularities occurred. In the case of Reference Example, yield resistance was low but impact toughness was excellent and surface irregularities did not occur.

[0088] In the case of Inventive Examples 1, 3 to 5, an average grain size of the steel was 50 μm or less, and a number of the coarse grains having a grain size of at least 50 μm was less than 1 per cm². Accordingly, surface irregularities may not occur even when processed as a final structure product, thereby giving rise to excellent surface quality.

[0089] In contrast, in the case of Comparative Examples 1 and 2, to which the forging treatment was not applied, showed 10 and 5 coarse grains having a grain size of 150 μm or more per cm², respectively, which may give rise to surface irregularities. Furthermore, numbers of the coarse grains of the steel, having a grain size of at least 50 μm , are 4 and 3 per cm², respectively. This indicates that surface irregularities may occur when processed as a final structure product. As anisotropy indices of Comparative Examples 1 and 2 are less than 0.6, irregularity of physical properties may remarkably occur according to directionality of a material of the final structure product.

[0090] In the case of Comparative Example 3, of which the forging and cooling conditions do not meet the requirements of the present invention, an average grain size of the austenite structure is 18 μm , and a precipitate percentage is 4%.

Accordingly, no surface irregularities occurred, but impact toughness was reduced.

[0091] As illustrated in FIG. 1, the microstructure of the coarse slab surface layer before forging has become more refined after forging.

[0092] The slab of Inventive Example 1 was subject to forging such that a grain size of the surface layer structure becomes that in FIG. 7 and was observed with respect to changes in high temperature ductility according to the grain size of the surface layer of the slab after forging. As illustrated in FIG. 7, a result indicates that the finer the grain size of the surface layer structure of the slab is, the more excellent the high temperature ductility of the slab is.

[0093] As shown in FIGS. 3 and 4, in the case of Inventive Example 3, to which the forging is applied according to the present invention, was shown to be more refined compared to Comparative Example 2, in which the steel structure was not forged after hot-rolled.

[0094] While exemplary embodiments have been shown and described above, the scope of the present disclosure is not limited thereto, and it will be apparent to those skilled in the art that modifications and variations could be made without departing from the scope of the present invention as defined by the appended claims.

Claims

1. A high manganese steel for low temperature applications, comprising:

0.3 wt% to 0.8 wt% of C, 18 wt% to 26 wt% of Mn, 0.01 wt% to 1 wt% of Si, 0.01 wt% to 0.5 wt% of Al, 0.1 wt% or less of Ti excluding 0%, 1 wt% to 4.5 wt% of Cr, 0.1 wt% to 0.9 wt% of Cu, 0.03 wt% or less of S excluding 0%, 0.3 wt% or less of P excluding 0%, 0.001 wt% to 0.03 wt% of N, 0.004 wt% or less of B excluding 0%, and a remainder of Fe and other inevitable impurities,

wherein a microstructure comprises an austenite single phase structure,

an average grain size of the austenite is 20 μm to 50 μm , and

a number of austenite grains having a grain size of 50 μm or more is less than 1 per cm^2 ,

wherein the high manganese steel further comprises 1 volume% or less, including 0%, of a precipitate,

wherein the high manganese steel has rolling direction impact toughness of 100 J or higher at -196°C ,

wherein the high manganese steel has an anisotropy index of 0.6 or higher, wherein the anisotropy index is a

ratio of thickness direction impact toughness at -196°C to rolling direction impact toughness at -196°C , and

wherein the high manganese steel has a yield strength of 400 MPa or higher.

2. The high manganese steel of claim 1, wherein an average grain size of the austenite structure is 20 μm to 30 μm .

3. The high manganese steel of claim 1, wherein, in the austenite structure, a number of austenite grains having a grain size of 30 μm or more is less than 1 per cm^2 .

4. The high manganese steel of claim 1, wherein the high manganese steel has a thickness of 8.0 mm to 40 mm.

5. A method of manufacturing a high manganese steel for low temperature applications according to claim 1, the method comprising:

preparing a slab comprising 0.3 wt% to 0.8 wt% of C, 18 wt% to 26 wt% of Mn, 0.01 wt% to 1 wt% of Si, 0.01 wt% to 0.5 wt% of Al, 0.1 wt% or less of Ti excluding 0%, 1 wt% to 4.5 wt% of Cr, 0.1 wt% to 0.9 wt% of Cu, 0.03 wt% or less of S excluding 0%, 0.3 wt% or less of P excluding 0%, 0.001 wt% to 0.03 wt% of N, 0.004 wt% or less of B excluding 0%, and a remainder of Fe and other inevitable impurities;

deformation application involving applying a deformation to the slab such that a recrystallization microstructure is formed on a surface layer portion of the slab;

air cooling involving air-cooling the slab on which the recrystallization microstructure is formed on the surface layer portion thereof to room temperature;

reheating involving heating the air-cooled slab to 1100°C to 1250°C ;

hot rolling involving finish-rolling the reheated slab at 850°C to 950°C to obtain a hot-rolled steel; and

accelerated cooling involving accelerated-cooling the hot-rolled steel at a cooling speed of $10^\circ\text{C}/\text{sec}$ or more to a accelerated cooling termination temperature of 600°C or less,

wherein the deformation application is performed such that a number of grains having a grain size of at least 150 μm on the surface layer portion that is a region of the slab surface layer portion up to 2 mm from the surface in a slab thickness direction is less than 1 per cm^2 , and

wherein the deformation application is performed such that a thickness reduction rate is 15% to 50% for an initial slab.

- 5 6. The method of claim 5, wherein the deformation application is performed by rough rolling under a high reduction condition at 1000°C to 1200°C or high temperature forging at 1000°C to 1200°C.
7. The method of claim 5, wherein an average grain size of the surface layer portion of the slab after the deformation application is 100 μm or less.
- 10 8. The method of claim 5, wherein, in the hot rolling, a final pass rolling temperature during hot finish rolling is 850°C or above and less than 900°C when a final thickness of the steel is 18t, wherein t: steel thickness in mm, or above, and a final pass rolling temperature during hot finish rolling is 900°C to 950°C 18t, when a final thickness of the steel is less than wherein t: steel thickness in mm.
- 15 9. The method of claim 5, wherein, in the hot rolling, a reduction ratio is at least 40% of a total reduction rate at a temperature below a non-recrystallization temperature (T_{nr}) 18t, wherein t: when a final thickness of the steel is steel thickness in mm or above.
- 20 10. The method of claim 5, wherein the hot-rolled steel has a thickness of 8 mm to 40 mm.

Patentansprüche

- 25 1. Hochmanganhaltiger Stahl für Niedertemperaturanwendungen, der Folgendes umfasst:
- 0,3 Gew.-% bis 0,8 Gew.-% C, 18 Gew.-% bis 26 Gew.-% Mn, 0,01 Gew.-% bis 1 Gew.-% Si, 0,01 Gew.-% bis 0,5 Gew.-% Al, 0,1 Gew.-% oder weniger Ti, ausschließlich 0 %, 1 Gew.-% bis 4,5 Gew.-% Cr, 0,1 Gew.-% bis 0,9 Gew.-% Cu, 0,03 Gew.-% oder weniger S, ausschließlich 0 %, 0,3 Gew.-% oder weniger P, ausschließlich 0 %, 0,001 Gew.-% bis 0,03 Gew.-% N, 0,004 Gew.-% oder weniger B, ausschließlich 0 %, und einen Rest von Fe und anderen unvermeidlichen Verunreinigungen, wobei eine Mikrostruktur eine einphasige Austenitstruktur umfasst, eine durchschnittliche Korngröße des Austenits 20 μm bis 50 μm beträgt und eine Anzahl von Austenitkörnern, die eine Korngröße von 50 μm oder mehr aufweisen, weniger als 1 pro cm² beträgt, wobei der hochmanganhaltige Stahl ferner 1 Volumen-% oder weniger, einschließlich 0 %, eines Niederschlags umfasst, wobei der hochmanganhaltige Stahl eine Schlagzähigkeit in Walzrichtung von 100 J oder höher bei -196 °C aufweist, wobei der hochmanganhaltige Stahl einen Anisotropieindex von 0,6 oder höher aufweist, wobei der Anisotropieindex ein Verhältnis von Schlagzähigkeit in Dickenrichtung bei -196 °C zu Schlagzähigkeit in Walzrichtung bei -196 °C ist, und wobei der hochmanganhaltige Stahl eine Streckgrenze von 400 MPa oder höher aufweist.
- 30 2. Hochmanganhaltiger Stahl nach Anspruch 1, wobei eine durchschnittliche Korngröße der Austenitstruktur 20 μm bis 30 μm beträgt.
3. Hochmanganhaltiger Stahl nach Anspruch 1, wobei in der Austenitstruktur eine Anzahl von Austenitkörnern, die eine Korngröße von 30 μm oder mehr aufweisen, weniger als 1 pro cm² beträgt.
- 40 4. Hochmanganhaltiger Stahl nach Anspruch 1, wobei der hochmanganhaltige Stahl eine Dicke von 8,0 mm bis 40 mm aufweist.
5. Verfahren zum Fertigen eines hochmanganhaltigen Stahls für Niedertemperaturanwendungen nach Anspruch 1, wobei das Verfahren Folgendes umfasst:
- 55 Vorbereiten einer Bramme, die 0,3 Gew.-% bis 0,8 Gew.-% C, 18 Gew.-% bis 26 Gew.-% Mn, 0,01 Gew.-% bis 1 Gew.-% Si, 0,01 Gew.-% bis 0,5 Gew.-% Al, 0,1 Gew.-% oder weniger Ti, ausschließlich 0 %, 1 Gew.-% bis 4,5 Gew.-% Cr, 0,1 Gew.-% bis 0,9 Gew.-% Cu, 0,03 Gew.-% oder weniger S, ausschließlich 0 %, 0,3 Gew.-%

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- 5 % oder weniger P, ausschließlich 0 %, 0,001 Gew.-% bis 0,03 Gew.-% N, 0,004 Gew.-% oderweniger B, ausschließlich 0 %, und einen Rest von Fe und anderen unvermeidlichen Verunreinigungen umfasst; Verformungsanwendung, die das Anwenden einer Verformung auf die Bramme einschließt, derart, dass eine Rekristallisationsmikrostruktur auf einem Oberflächenschichtabschnitt der Bramme ausgebildet wird;
- 10 Luftkühlen, das das Luftkühlen der Bramme, auf der die Rekristallisationsmikrostruktur auf dem Oberflächenschichtabschnitt davon ausgebildet ist, auf Raumtemperatur einschließt;
- 15 Wiedererwärmen, das ein Erwärmen der luftgekühlten Bramme auf 1100 °C bis 1250 °C einschließt;
- Warmwalzen, das ein Feinwalzen der wiedererwärmten Bramme bei 850 °C bis 950 °C einschließt, um einen warmgewalzten Stahl zu erhalten; und
- 20 beschleunigtes Kühlen, das das beschleunigte Kühlen des warmgewalzten Stahls mit einer Kühlgeschwindigkeit von 10 °C/s oder mehr auf eine Endtemperatur des beschleunigten Kühlens von 600 °C oder weniger einschließt, wobei die Verformungsanwendung derart durchgeführt wird, dass eine Anzahl von Körnern, die eine Korngröße von wenigstens 150 µm auf dem Oberflächenschichtabschnitt aufweisen, der eine Region des Brammenoberflächenschichtabschnitts bis zu 2 mm von der Oberfläche in einer Brammendickenrichtung entfernt ist, weniger
- 25 als 1 pro cm² ist und wobei die Verformungsanwendung derart durchgeführt wird, dass eine Dickenreduktionsrate 15 % bis 50 % für eine anfängliche Bramme beträgt.
- 30 6. Verfahren nach Anspruch 5, wobei die Verformungsanwendung durch Vorwalzen unter einer Hochreduktionsbedingung bei 1000 °C bis 1200 °C oder Hochtemperaturschmieden bei 1000 °C bis 1200 °C durchgeführt wird.
7. Verfahren nach Anspruch 5, wobei eine durchschnittliche Korngröße des Oberflächenschichtabschnitts der Bramme nach der Verformungsanwendung 100 µm oder weniger beträgt.
- 25 8. Verfahren nach Anspruch 5, wobei bei dem Warmwalzen eine Schlichtstichwalztemperatur während des Warmfeinwalzens 850 °C oder darüber und weniger als 900 °C beträgt, wenn eine Enddicke des Stahls 18 t, wobei t: Stahldicke in mm, oder darüber beträgt, und eine Schlichtstichwalztemperatur während des Warmfeinwalzens 900 °C bis 950 °C beträgt, wenn eine Enddicke des Stahls weniger als 18 t beträgt, wobei t: Stahldicke in mm.
- 30 9. Verfahren nach Anspruch 5, wobei bei dem Warmwalzen ein Reduktionsverhältnis wenigstens 40 % einer Gesamtreduktionsrate bei einer Temperatur unterhalb einer Nicht-Rekristallisationstemperatur (T_{nr}) beträgt, wenn eine Enddicke des Stahls 18 t, wobei t: Stahldicke in mm, oder darüber beträgt.
- 35 10. Verfahren nach Anspruch 5, wobei der warmgewalzte Stahl eine Dicke von 8 mm bis 40 mm aufweist.

Revendications

- 40 1. Acier à haute teneur en manganèse pour des applications à basse température, comprenant :
- 45 0,3 % en poids à 0,8 % en poids de C, 18 % en poids à 26 % en poids de Mn, 0,01 % en poids à 1 % en poids de Si, 0,01 % en poids à 0,5 % en poids d'Al, 0,1 % en poids ou moins de Ti à l'exclusion de 0 %, 1 % en poids à 4,5 % en poids de Cr, 0,1 % en poids à 0,9 % en poids de Cu, 0,03 % en poids ou moins de S à l'exclusion de 0 %, 0,3 % en poids ou moins de P à l'exclusion de 0 %, 0,001 % en poids à 0,03 % en poids de N, 0,004 % en poids ou moins de B à l'exclusion de 0 %, et un reste de Fe et d'autres impuretés inévitables,
- 50 une microstructure comprenant une structure monophasée austénitique, une taille de grain moyenne de l'austénite étant de 20 µm à 50 µm, et un nombre de grains d'austénite ayant une taille de grain égale ou supérieure à 50 µm étant inférieur à 1 par cm², l'acier à haute teneur en manganèse comprenant en outre 1 % en volume ou moins, y compris 0 %, d'un précipité,
- 55 l'acier à haute teneur en manganèse ayant une résistance au choc dans le sens du laminage égale ou supérieur à 100 J à -196 °C, l'acier à haute teneur en manganèse ayant un indice d'anisotropie égal ou supérieur à 0,6, l'indice d'anisotropie étant un rapport de résistance au choc dans le sens de l'épaisseur à -196 °C à la résistance au choc dans le sens du laminage à -196 °C, et l'acier à haute teneur en manganèse ayant une limite d'élasticité égale ou supérieure à 400 MPa.
2. Acier à haute teneur en manganèse selon la revendication 1, une taille de grain moyenne de la structure austénitique étant de 20 µm à 30 µm.

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3. Acier à haute teneur en manganèse selon la revendication 1, dans la structure austénitique, un nombre de grains d'austénite ayant une taille de grain égale ou supérieure à 30 μm étant inférieur à 1 par cm^2 .

4. Acier à haute teneur en manganèse selon la revendication 1, l'acier à haute teneur en manganèse ayant une épaisseur de 8,0 mm à 40 mm.

5. Procédé de fabrication d'un acier à haute teneur en manganèse pour des applications à basse température selon la revendication 1, le procédé comprenant :

la préparation d'une brame comprenant 0,3 % en poids à 0,8 % en poids de C, 18 % poids à 26 % en poids de Mn, 0,01 % en poids à 1 % en poids de Si, 0,01 % en poids à 0,5 % en poids d'Al, 0,1 % en poids ou moins de Ti à l'exclusion de 0 %, 1 % en poids à 4,5 % en poids de Cr, 0,1 % en poids à 0,9 % en poids de Cu, 0,03 % en poids ou moins de S à l'exclusion de 0 %, 0,3 % en poids ou moins de P à l'exclusion de 0 %, 0,001 % en poids à 0,03 % en poids de N, 0,004 % en poids ou moins de B à l'exclusion de 0 %, et un reste de Fe et d'autres impuretés inévitables ;

l'application de déformation impliquant l'application d'une déformation sur la brame de telle sorte qu'une microstructure de recristallisation est formée sur une partie de couche de surface de la brame ;

le refroidissement par air impliquant le refroidissement par air de la brame sur laquelle la microstructure de recristallisation est formée sur sa partie de couche de surface à température ambiante ;

le réchauffement impliquant le chauffage de la brame refroidie par air entre 1 100 °C et 1 250 °C ;

le laminage à chaud impliquant le laminage de finition de la brame réchauffée de 850 °C à 950 °C pour obtenir un acier laminé à chaud ; et

le refroidissement accéléré impliquant le refroidissement accéléré de l'acier laminé à chaud à une vitesse de refroidissement égale ou supérieure à 10 °C/sec jusqu'à une température de terminaison de refroidissement accélérée égale ou inférieure à 600 °C,

l'application de déformation étant effectuée de telle sorte qu'un nombre de grains ayant une taille de grain d'au moins 150 μm sur la partie de couche de surface qui est une région de la partie de couche de surface de brame jusqu'à 2 mm de la surface dans une direction d'épaisseur de brame est inférieur de 1 par cm^2 , et

l'application de déformation étant effectuée de telle sorte qu'un taux de réduction d'épaisseur est de 15 % à 50 % pour une brame initiale.

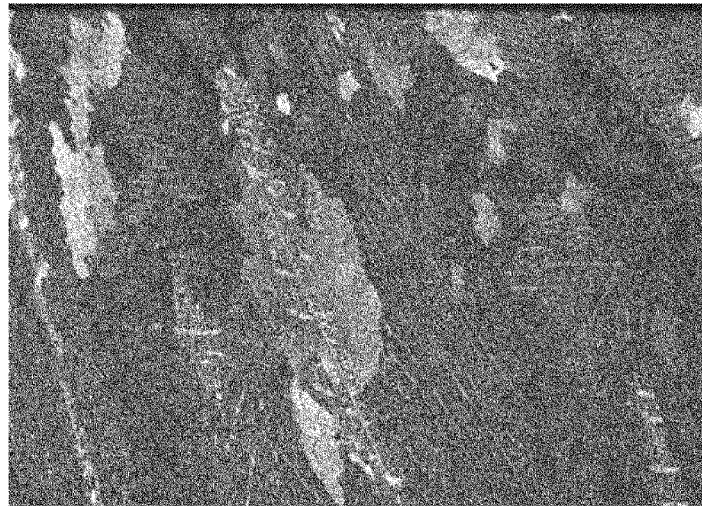
6. Procédé selon la revendication 5, l'application de déformation étant effectuée par laminage brut dans une condition de haute réduction entre 1 000 °C et 1 200 °C ou par forgeage à haute température entre 1 000 °C et 1 200 °C.

7. Procédé selon la revendication 5, une taille de grain moyenne de la partie de couche de surface de la brame après l'application de déformation étant égale ou inférieure à 100 μm .

8. Procédé selon la revendication 5, dans le laminage à chaud, une température de laminage à passage final pendant le laminage de finition à chaud étant égale ou supérieure à 850 °C et inférieure à 900 °C lorsqu'une épaisseur finale de l'acier est égale ou supérieure à 18t, t : épaisseur de l'acier en mm, et une température de laminage à passage final pendant le laminage de finition à chaud étant de 900 °C à 950 °C lorsqu'une épaisseur finale de l'acier est inférieure à 18t, t : épaisseur de l'acier en mm.

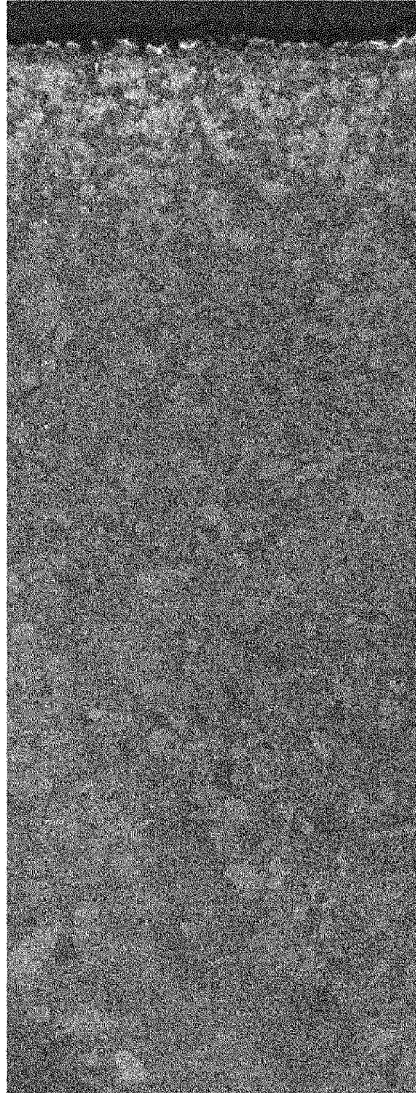
9. Procédé selon la revendication 5, dans le laminage à chaud, un rapport de réduction étant d'au moins 40 % d'un taux de réduction total à une température inférieure à une température de non-recristallisation (T_{nr}) lorsqu'une épaisseur finale de l'acier est égale ou supérieure à 18t, t : épaisseur de l'acier en mm.

10. Procédé selon la revendication 5, l'acier laminé à chaud ayant une épaisseur de 8 mm à 40 mm.



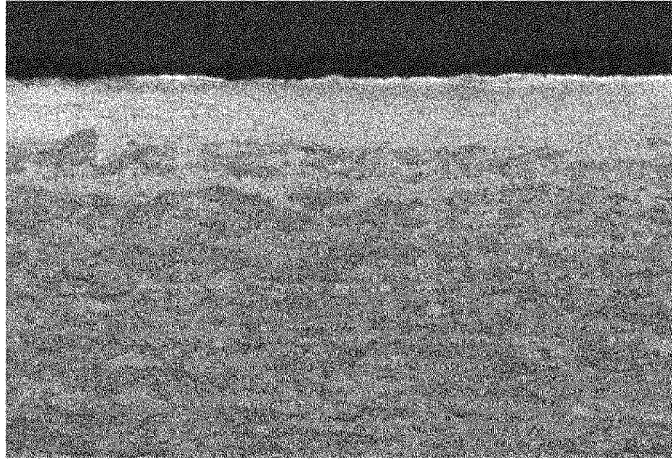
1000 μ m

FIG. 1



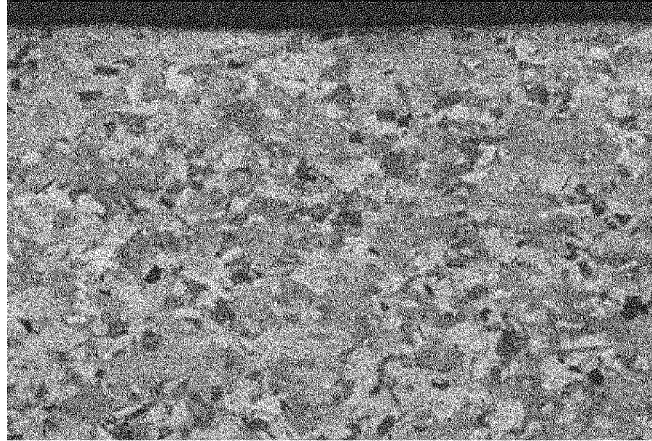
$\overline{200\mu\text{m}}$

FIG. 2



50 μ m

FIG. 3



50 μ m

FIG. 4

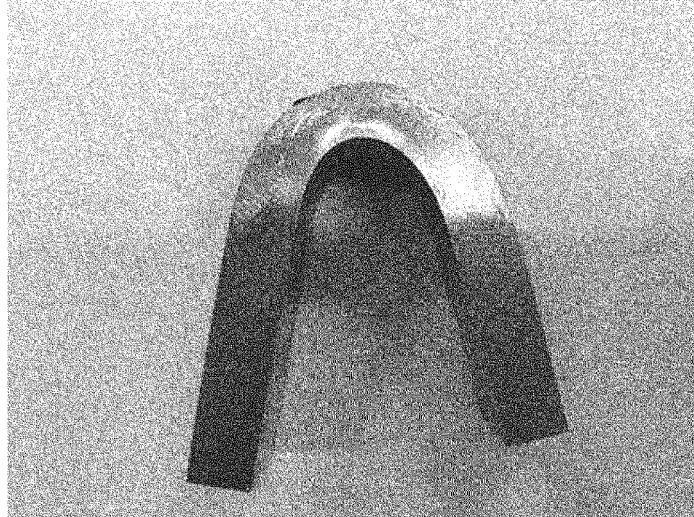


FIG. 5

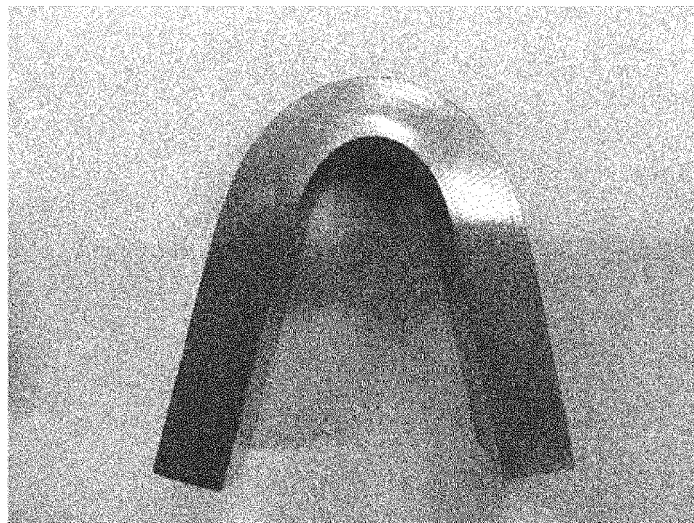


FIG. 6

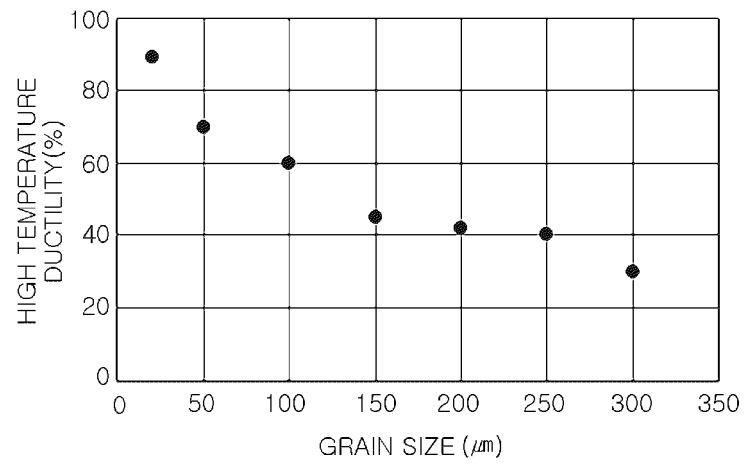


FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- KR 20110009792 [0010]
- WO 2016105002 A1 [0010]